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# PROGRESS WITH THE 2Q-LEBT FACILITY FOR THE RIA PROJECT\*

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## Abstract

The design goal of 400 kW uranium beam in the Rare Isotope Accelerator (RIA) Driver Linac can be achieved employing a concept of simultaneous acceleration of two charge states. It has been undertaken to build a prototype 2Q-injector of the RIA Driver Linac which includes an ECR ion source, a LEBT and one-segment of the prototype RFQ. The project called the 2Q-LEBT Facility is being developed in the Physics Division of ANL. Currently, the 2Q-LEBT Facility consists of BIE-100 ECR ion source. The reassembly and commissioning of the source has been completed. During the commissioning process we redesigned and manufactured a few components of the source to increase the beam production performance. A new diagnostic station has been designed and built for accurate measurements of the output beam emittance. The further development of the 2Q-LEBT Facility comprises installation of the source on 100 kV high-voltage platform, building an achromatic bending and transport system including the multi-harmonic buncher, and a full power 57.5 MHz RFQ segment. This report includes a detailed description of the 2Q-LEBT design and beam dynamics simulations along with emittance measurements for various beams.

## INTRODUCTION

Acceleration of a two-charge-state beam was proposed as a basic conception of the RIA Driver Linac [1]. The further analysis of this approach by means of comprehensive beam dynamics simulations has resulted in a preliminary design of the RIA Front End [2]. It will consist of an ECR ion source, the only type of source capable of producing a multiple-charge-state beam in the cw regime, a low energy beam transport (LEBT), a 57.5 MHz RFQ [3], and a medium energy beam transport (MEBT). The ion source will be located on 100 kV high-voltage platform for initial acceleration of the beam. The LEBT includes an achromatic bend system consisting of two 60° bending magnets for charge-to-mass analysis that can select the required one- or two-charge-state heavy-ion beam and a straight section comprising a multi-harmonic buncher, velocity equalizer and transverse focusing elements to form the high quality dual charge-state beam with total transverse normalized emittance of  $\sim 0.6 \pi$  mm-mrad and longitudinal emittance  $\sim 2 \pi$  keV/u-nsec at 99.5% level of total intensity. The straight section of the LEBT will be placed on a 30 kV high-voltage deck in order to match the velocities of ions with charge-to-mass ratio less than the design value. The numerical simulation studies are mostly completed and it was decided to build a

full-scale prototype of the RIA Driver Front End consisting of the ECR ion source on a 100 kV high-voltage platform, the LEBT and one segment of the 57 MHz RFQ. The ultimate goals of this project are to verify the concept of acceleration of a dual charge-state beam, to confirm the low-emittance performance of the LEBT and RFQ, to test the gridless multi-harmonic buncher, to demonstrate the stable operation of the 57 MHz RFQ over a wide range of rf power, and to establish the final specification for the RIA Driver Front End. Development of this project is currently in progress.

## DESCRIPTION OF THE 2Q-LEBT FACILITY

At present, the 2Q-LEBT Facility consists of a BIE-100 ECR ion source, 90° bending magnet and beam diagnostic station. The ion source was designed and built by Berkeley Ion Equipment Corporation [4] and transferred to ANL with related equipment as part of the termination of a SBIR Phase II project. The BIE-100 is an all-permanent-magnet source utilizing NdFeB magnetic material and is the first all-permanent-magnet source developed in the USA. It has a number of advantages compared to ion sources built with electromagnets such as simpler source structure, easier operation and lower power consumption. An additional important feature is the possibility to bias the source up to 30 kV or higher for better ion beam extraction and transport. The BIE-100 operates with the possibility of two-frequency plasma heating. The 12.75 GHz rf power is provided by a 650 W traveling wave tube amplifier (TWTA) while the microwaves at 14.5 GHz are produced by a 2 kW klystron amplifier. Both amplifiers were manufactured by Communications & Power Industries (CPI). Two separate rf drivers are used to generate the input signals to the amplifiers. Currently, the BIE-100 operates at only the primary frequency of 14.5 GHz due to breakdown of the traveling wave tube in the TWTA. Two-frequency heating will be restored as soon as the replacement tube is received. Reassembly and commissioning of the BIE-100 ion source have been completed at ANL [5]. During the commissioning process, a number of modifications were implemented to increase the beam production performance of the original source. A new Einzel lens, a puller, a high-voltage insulator between source body and main beamline have been fabricated. Additionally, we have redesigned the injection assembly and evaporation oven, and equipped the facility with a new interlock system. A dipole magnet has been installed in the beamline downstream of the Einzel lens for vertical steering of the beam. In some cases, adjustment of the beam position in vertical direction allows us to increase output current by 30%.

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The diagnostic station includes a system of adjustable slits, a removable Faraday cup and an Emittance Measurement Device (EMD), see Fig. 1. The slit system consists of four linear actuators with rectangular plates on each one thus forming one vertical and one horizontal slit of adjustable width. The emittance scanner is based on a conventional combination of a narrow slit and wire for each transverse direction. Two EMD slits are cut in the same tantalum plate, which is inserted into the beamline by a linear actuator orientated at  $45^\circ$  with respect to the vertical line. The slits are perpendicular to each other and cut at  $45^\circ$  with respect to the axis of actuator motion. Therefore, the beam is collimated first by the vertical and then by the horizontal slit during one linear movement. The scanning wires work the same way. The remote control of the EMD equipment, data acquisition and data analysis are provided by user-friendly software implemented using LabVIEW 6.1. The code affords transverse beam profiles, emittances and Twiss parameters online.

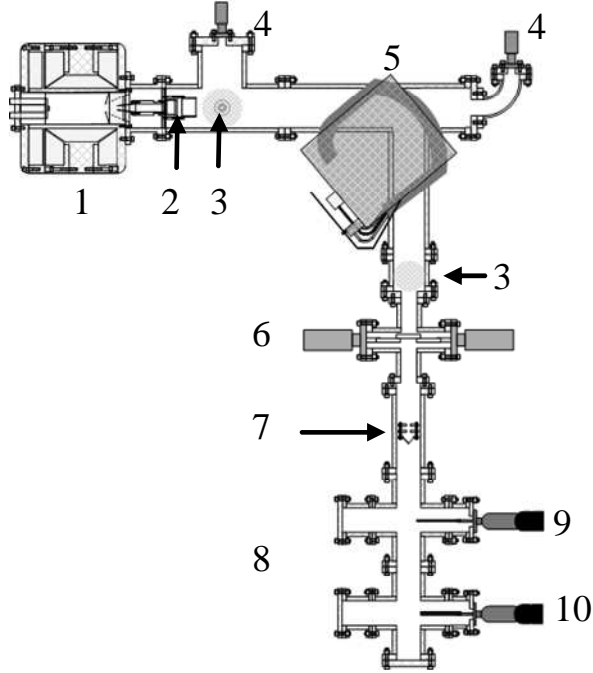


Figure 1. Current layout of the 2Q-LEBT Facility: 1-source body; 2-Einzel lens; 3-turbo pump; 4-vacuum gauge; 5-analyzing magnet; 6-slit system; 7-Faraday cup; 8-EMD; 9-EMD slits actuator; 10-EMD target wires actuator.

## BEAM DYNAMICS SIMULATIONS

Numerical studies of beam dynamics in the 2Q-LEBT have been performed using the multi-particle code TRACK [6] developed especially for RIA design purposes. TRACK simulates a multiple-charge-state beam dynamics through preliminary calculated 3D beam-optics fields taking into account space-charge effects. The realistic geometry of the present 2Q-LEBT beamline shown in Fig. 1 was set up in the TRACK model. The two-dimensional electrostatic fields in the initial part of beamline that consists of puller, Einzel lens and grounded

electrodes were calculated using the POISSON code (see Fig. 2). A 3D representation of magnetic field of the  $90^\circ$  bending magnet, including fringing fields, was also used. The phase space distribution parameters of the input beam were optimized to fit the measured output beam emittance. Figure 3 illustrates the comparison between the measured and calculated data for the case of Xenon beam. The simulations have been performed for  $3 \cdot 10^5$  particles including space charge effects. The RMS Twiss parameters of the beam for this example are listed in the Table 1. As is seen, the developed model provides a reasonable agreement with experimental results and can be used for further design of the Facility.

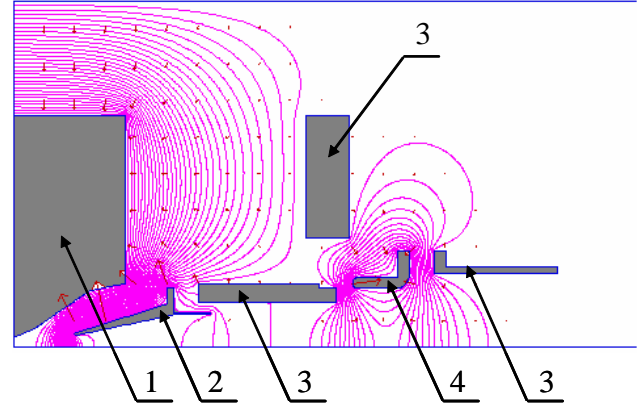


Figure 2. Initial part of the 2Q-LEBT beamline in the POISSON model: extraction electrode (1); puller (2); grounded electrodes (3) and Einzel lens (4).

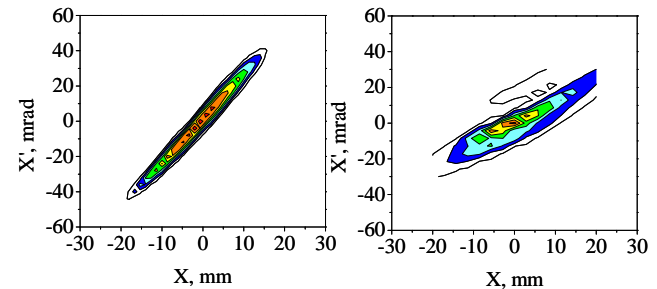


Figure 3. Calculated (left) and measured (right) emittance of  $^{128}\text{Xe}^{13+}$  beam.

Table 1. Calculated and measured Twiss parameters of  $^{128}\text{Xe}^{13+}$  beam.

Beam	RMS Emittance, $\pi \cdot \text{mm} \cdot \text{mrad}$	RMS $\alpha$	RMS $\beta$ , $\text{mm/mrad}$
Measured output	0.051	-4.76	3
Calculated output	0.06	-5.6	2.25
Calculated input	0.055	0	0.1

## BEAM MEASUREMENTS

Presently, we are carrying out wide-ranging studies with various beams at the 2Q-LEBT Facility. Figure 4 shows an example of Argon beam charge state distribution measured at 400 W rf power and 20 kV source bias. The beam current in this experiment is relatively low due to the use of only one rf transmitter for plasma heat. The high intensity beam production test will be done as soon as the TWT amplifier is available.

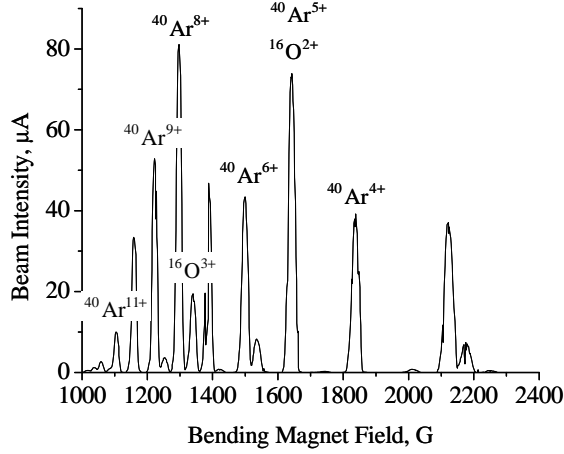


Figure 4. Argon beam spectrum.

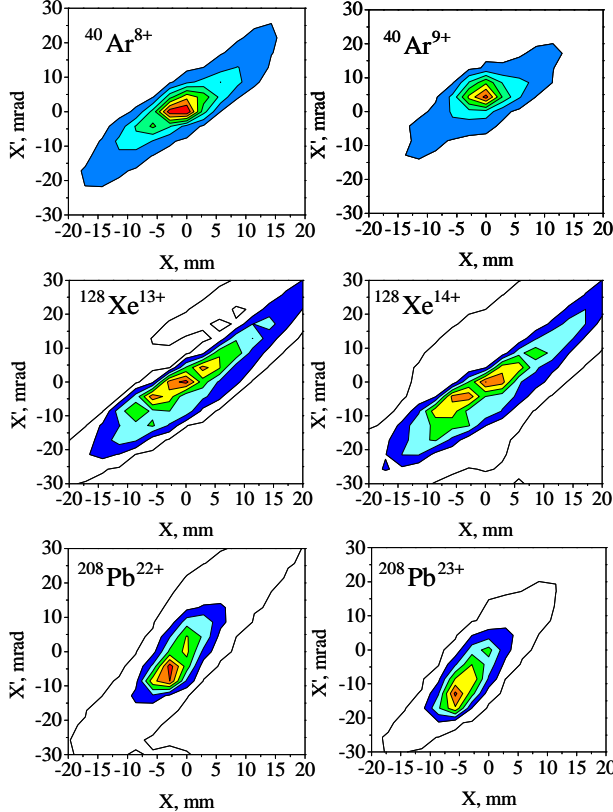


Figure 5. Typical emittance patterns for Argon, Xenon and Lead beams.

A few typical patterns of measured beam emittances are shown in Figure 5. Accurate treat of the measured data was performed to verify that the ECR source forms a

beam with similar phase space distributions of the neighboring charge states, which is essential for the simultaneous acceleration of two charge states as required for RIA. As is seen from Table 2, Twiss parameters of different charge states generated by the BIE-100 are very close to each other. At this stage of the project, operation of the ion source and its beam production performance are sufficient to proceed with further modifications of the Facility.

Table 2. Phase space distribution parameters for sample Argon, Xenon and Oxygen beams. Columns: 1-ion species, 2-intensity (eμA), 3-normalised RMS emittance ( $\pi \cdot \text{mm} \cdot \text{mrad}$ ), 4-RMS  $\alpha$ , 5-RMS  $\beta$  (mm/mrad).

1	2	3	4	5
Pb <sup>21+</sup>	15	0.053	-2.6	2.39
Pb <sup>22+</sup>	14.5	0.05	-2.31	1.55
Pb <sup>23+</sup>	14	0.049	-2.24	1.65
Xe <sup>12+</sup>	25	0.056	-4.32	2.73
Xe <sup>13+</sup>	22	0.051	-4.76	3.00
Xe <sup>14+</sup>	19	0.055	-4.71	3.03
Ar <sup>7+</sup>	22	0.07	-2.08	1.23
Ar <sup>8+</sup>	49	0.07	-1.9	1.28
Ar <sup>9+</sup>	19	0.05	-2.3	1.18

## FURTHER DEVELOPMENT

Design of the 100 kV high-voltage deck has been completed. Incorporation of the platform along with an isolation power transformer, safety fence and related equipment into the 2Q-LEBT Facility will be accomplished during summer 2005. The 57 MHz RFQ segment is being fabricated now. The final specifications for the 60° bending magnets and accelerating tube with subsequent manufacturing are expected in fall 2005. Therefore, we plan to finish assembly of the full-scale prototype of the RIA Driver Front End and commission the full facility in the beginning of 2006.

## REFERENCES

- [1] P.N. Ostroumov et al., Proc. of the 2000 Linac Conf., Monterey, August 2000, SLAC-R-561, p. 202.
- [2] A.A. Kolomiets et al., Proc. of the 2003 PAC Conf., Portland, OR, May 2003, p. 2876.
- [3] P.N. Ostroumov et al., Phys. Rev. ST Accel. Beams 5, 060101 (2002).
- [4] Dan Z. Xie, Rev. of Scient. Instr, vol. 73 (2), p. 531, 2002.
- [5] N.E. Vinogradov et al., Proc. of the ECRIS 2004 Conf., Berkeley, California, September 2004, p. 215.
- [6] P.N. Ostroumov et al., PRST-AB, vol. 7, 000101 (2004).